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MEASUREMENT AND ANALYSIS OF L- AND X-BAND MINE CROSS SECTIONS.(U)
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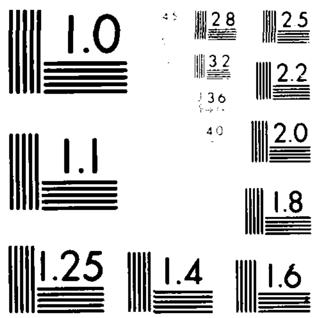

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MEASUREMENT AND ANALYSIS OF L- AND X-BAND MINE CROSS SECTIONS

A.L. MAFFETT AND E.L. JOHANSEN

AUGUST 1979

Prepared for
U.S. Army Mobility Equipment
Research and Development Command
Ft. Belvoir, VA

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The cross sections of several anti-tank mines including the Soviet TM-46 and East German PM-60 were measured at 1.2 and 1.65 GHz. In free space the median cross sections of these mines were about -13 and -20 dBsm, respectively. Calculations were made to determine the detectability of the anti-tank mines at L-band, and it was found that the mines do not increase the background reflectivity sufficiently to permit detection in clutter backgrounds typical of Eastern Europe.

4[illegible]

20. X-band cross section measurements were also made which showed that 1) the American M-15 is a good simulation for the TM-46 in radar tests and 2) the simulated PM-60s being manufactured for radar test purposes have the same cross section as a real PM-60. At a 10° depression angle, both the M-15 and the TM-46 have cross sections of -3 or -4 dBsm. The PM-60 and the simulated PM-60s both had cross sections of about -20 dBsm at the 10° depression angle.

Additional theoretical work is needed to adequately explain the RCS change with frequency (X- to L-band) and to account for scattering interaction between a mine and its ground plane, particularly at L-band.

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FIGURES (Continued)

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FOREWORD

The measurements and analyses described in this interim report were performed by or for the Environmental Research Institute of Michigan, Box 8618, Ann Arbor, Michigan. The Mine Detection Division of the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) at Fort Belvoir, Virginia sponsored the work under Contract DAAK70-78-C-0198.

Dr. J. Roland Gonano monitored the program for MERADCOM. Mr. Henry McKenney was the ERIM Program Manager, and Dr. Elmer Johansen was the task leader for the work covered in this report. The co-authors of the report are Professor Andrew Maffett, ERIM consultant and Dr. E.L. Johansen. Other ERIM personnel who participated in the measurements include Mr. Ralph Hamilton, Mr. Robert Huxtable, and Mr. LeRoy Kottke.

ERIM wishes to thank Mr. Joe Ferris of the Radiation Laboratory of the University of Michigan, who supervised the L-band measurements. All L-band measurements were made in the University of Michigan's anechoic chamber under a subcontract.

The ERIM report number for this document is 138300-27-T.

MEASUREMENT & ANALYSIS OF L AND X-BAND MINE CROSS SECTIONS

1
BACKGROUND

As a task of the Detection of Remote Minefields Program, ERIM is studying the applicability of various sensors to minefield detection. One of the generic classes of sensor is radar. So far the effort has concentrated on assessing the potential of X-band radar but for minefield detection there is also interest in using a frequency below X-band where soil and foliage penetration are better. The attenuation of microwave signal varies greatly with frequency, and the attenuation is high at X-band unless the moisture content of the soil is very low. At L-band the attenuation is much less, and the reflected signals from buried mines and soil disturbances may be different. At L-band the dimensions of the mine are comparable to the wavelength, and some observers have postulated that resonance effects might enhance the radar cross section (RCS).

For these reasons ERIM initiated an L-band measurement and analysis program. In the previous mine detection program, under Contract DAAK-70-77-C-0178, RCS measurements were made on four different mines at X-band while the mines were on a ground plane. These data were used to calculate the signal-to-clutter ratio of surface mines in clutter backgrounds (see Ref. 1). Since similar data were needed for L-band modeling, ERIM contracted with the Radiation Laboratory of the University of Michigan to measure mine cross sections at L-band in an anechoic chamber. Additional X-band measurements were also made in the current program, for two reasons. First, a Soviet TM-46 mine was not available in 1977 for RCS measurements; consequently, no data were available to determine whether the American M-15 mine was a good radar simulation for the TM-46. Both of these

1. Detection of Remote Minefields, ERIM Report No. 131000-11-F, March 1978 (CONFIDENTIAL-NOFORN).

mines have a metal case and they are approximately the same size and shape.

Secondly, the new measurements acquired RCS data on a real East German PM-60, a mine with a plastic case; in 1977 measurements were made only on simulated PM-60 mines supplied by MERADCOM. Measurements were also needed to determine if the RCS of the new simulated PM-60 being purchased under the program from Associated Fabricators, Inc. matched the RCS of the real PM-60. A question also arose as to whether a metal fuze and detonator would affect the PM-60 RCS.

Since the 1977 measurements ERIM has modified its X-band instrumentation. A tower with an antenna platform has been erected at the rotary platform instrumentation site. With the tower any depression angle between 0 and 24.8° is available; in 1977 data were collected primarily at a 4° depression angle. The 1979 measurements therefore presented an opportunity to obtain data at higher angles.

2
L-BAND CHAMBER MEASUREMENTS

The Radiation Laboratory made all L-band measurements in an anechoic chamber 50 ft in length, 30 ft in width and 15 ft in height. The distance from the antenna to the pedestal was 30 ft for the mine measurements. The ceiling, floor, and transmitting end wall of the chamber are covered with hairflex absorber, while the rear and side walls are covered with 18 inch pyramidal absorber. Figure 1 is a photograph of the chamber showing the antenna at the left and a calibration sphere on a pedestal at the right.

Three types of measurements were made; the mines were measured in free space, on a vertical ground plane, and on the metal floors of the chamber. The free space measurements went smoothly, but problems arose with the ground-plane measurements.

2.1 FREE SPACE MEASUREMENTS

The free space measurements were made using standard anechoic chamber procedures and instrumentation; the measurement frequencies were 1.65 and 1.2 GHz and the polarizations horizontal and vertical. The mines were mounted vertically on a foam pedestal normal to the incident field, and the returns were recorded as the mines rotated through a 360° angle. During the measurements the background signal was balanced out, a calibration reading was made with a 14 inch sphere, and then RCS data were collected from individual mines.

The mines of greatest importance are the TM-46 and the PM-60. Figure 2 shows the TM-46 on the foam pedestal in position for measurement; the TM-46 is a Soviet metal mine. The PM-60, Figure 3, is an East German plastic mine. For the measurements, the PM-60 was filled with wax having the same dielectric constant as the explosive with which it would normally be filled. The RCS of an American M-15 metal mine, a simulated PM-60 mine, a Soviet TMD-B wooden mine, and

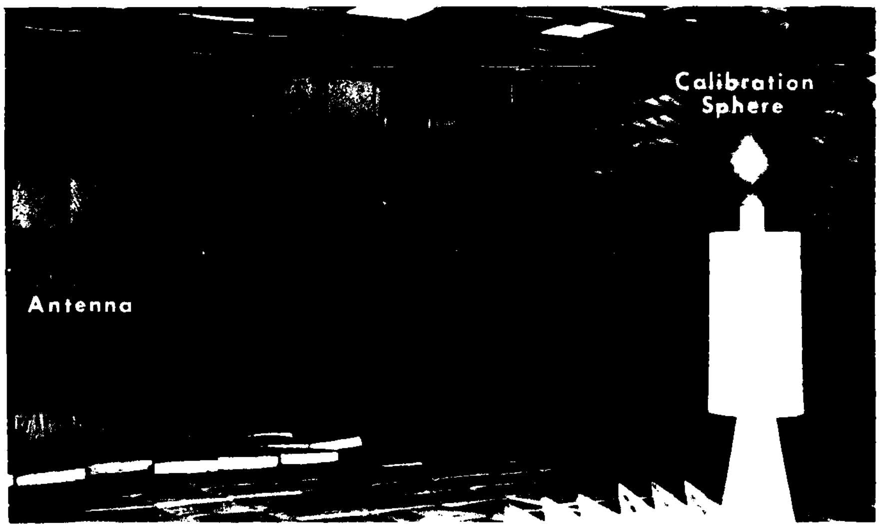


FIGURE 1. ANECHOIC CHAMBER WITH CALIBRATION SPHERE

FIGURE 2. TM-46 ON FOAM PEDESTAL

FIGURE 3. PM-60 ON FOAM PEDESTAL
(Rear View)

an American M-19 plastic mine were also measured. Figures 4-6 show three of the mines on the foam pedestal for free space measurements; Figure 7 shows the M-15 on a metal ground plane on the floor of the chamber. The M-15 data is important because the M-15 will simulate the TM-46 in radar mine detection experiments.

Figure 8 has sample free space patterns from the TM-46 at 1.2 and 1.65 GHz. The vertical scale is the relative RCS in dB, and the arrow at the right indicates the absolute RCS level derived from the 14 inch calibration sphere. The bottom scale is the incidence angle; at 0^{o} the front of the mine is facing the antenna. Figure 9 has sample patterns for the M-15 which is approximately the same size and shape as the TM-46. Figure 10 has the TMD-B and PM-60 simulation RCS. The PM-60 simulation, the white mine in Figure 4, was supplied by MERADCOM.

2.2 *GROUND PLANE MEASUREMENTS*

As mentioned previously, difficulties were encountered with the ground plane measurements and these difficulties could not be resolved within the scope of the task. Ideally, the mines should be measured on different types of terrain over a range of depression angles. For future measurements on ground planes, a pulsed system with a narrow antenna beam is recommended. Although an anechoic chamber gives excellent free-space measurements, a chamber is not well suited to making measurements over a range of depression angles with mines on dielectric ground planes. It is difficult to equip the chamber with a suitable dielectric ground plane, to vary the depression angle, and to calibrate the instrumentation in the presence of the ground plane.

For the initial ground-plane measurements a large metal ground plane was mounted on the pedestal normal to the floor of the chamber. The RCS of the ground plane alone and the ground plane with mines

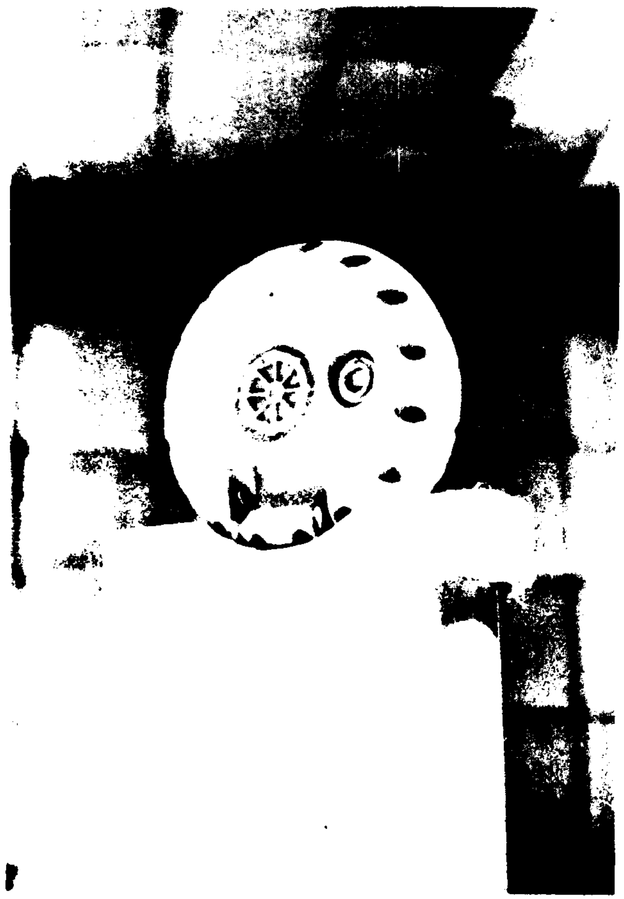


FIGURE 4. SIMULATED PM-60 ON FOAM PEDESTAL (Rear View)

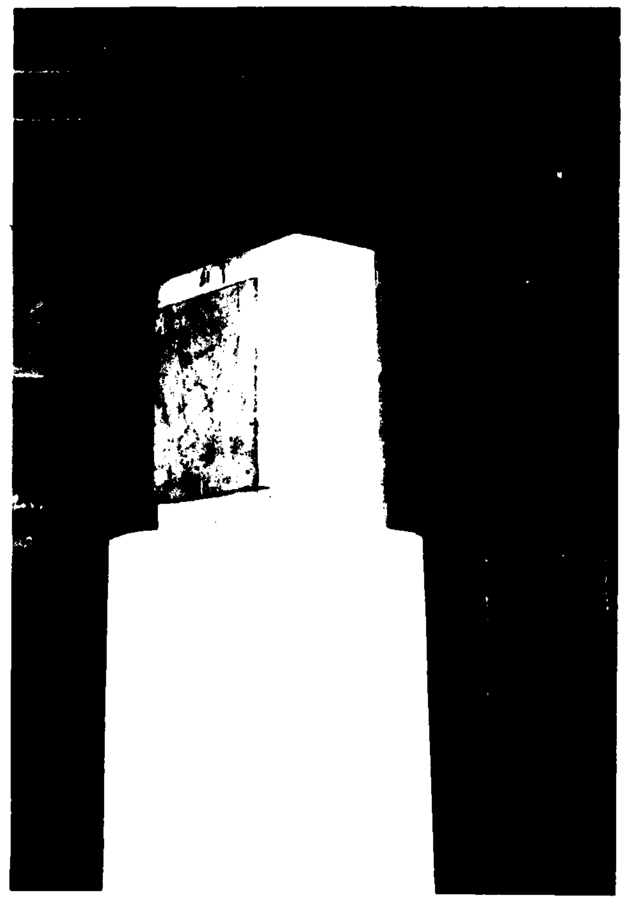


FIGURE 5. TMD-B ON FOAM PEDESTAL

FIGURE 6. M-19 ON FOAM PEDESTAL

FIGURE 7. M-15 ON METAL GROUND PLANE

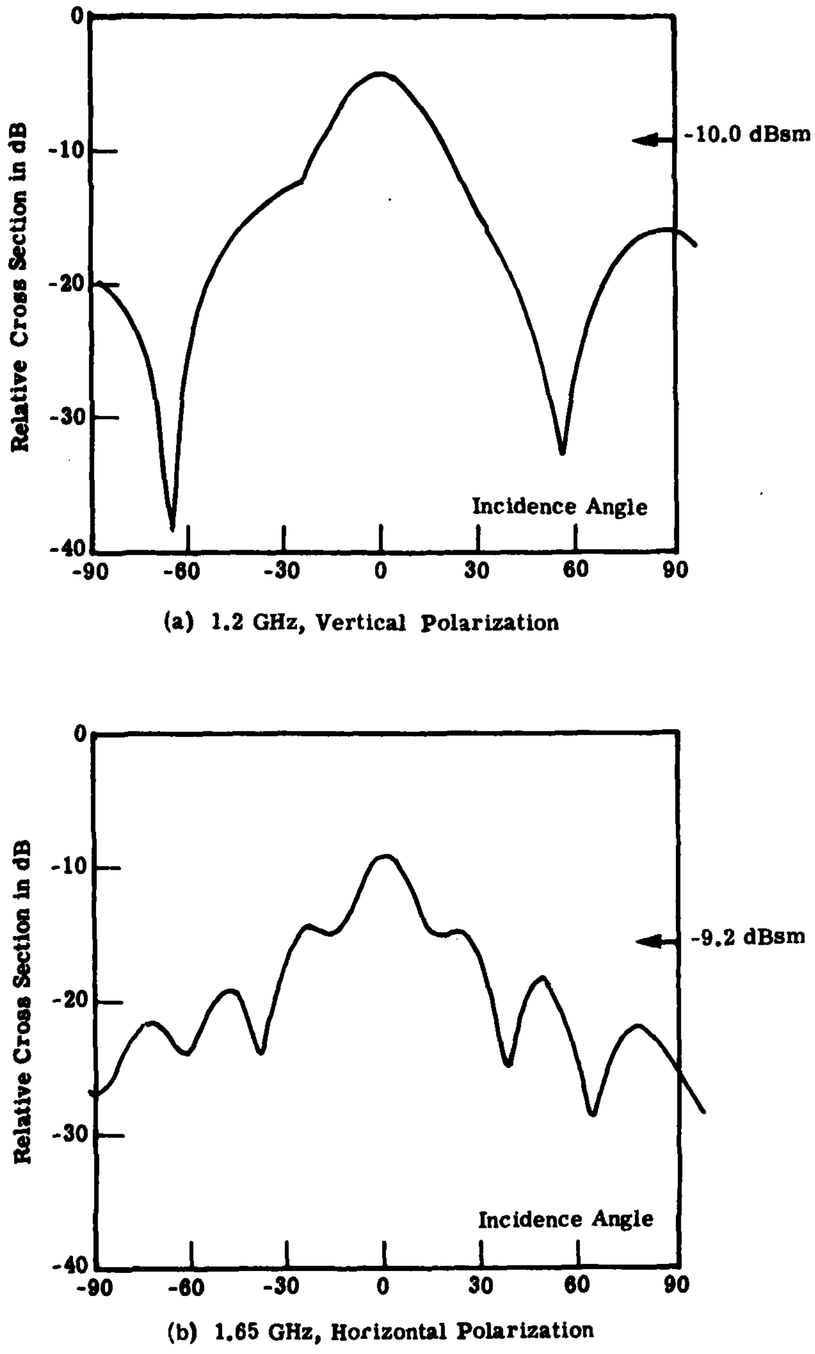
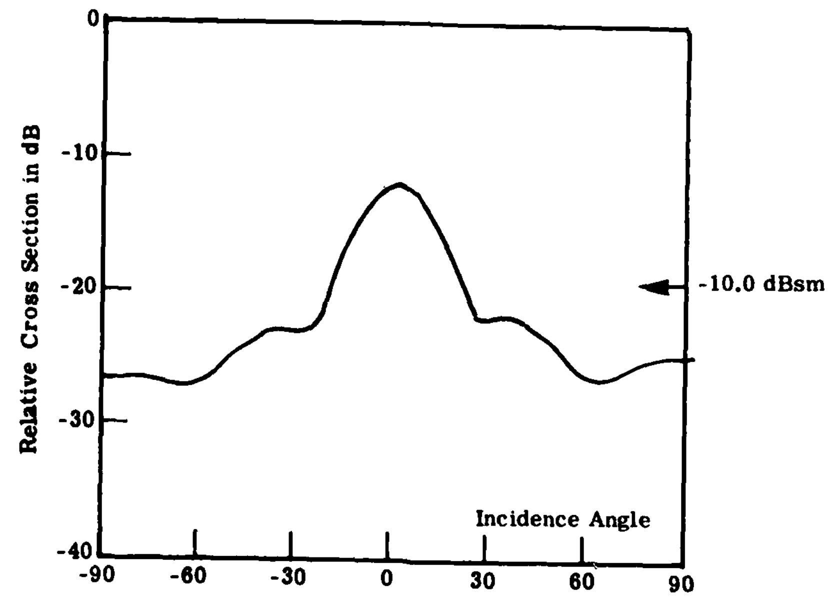
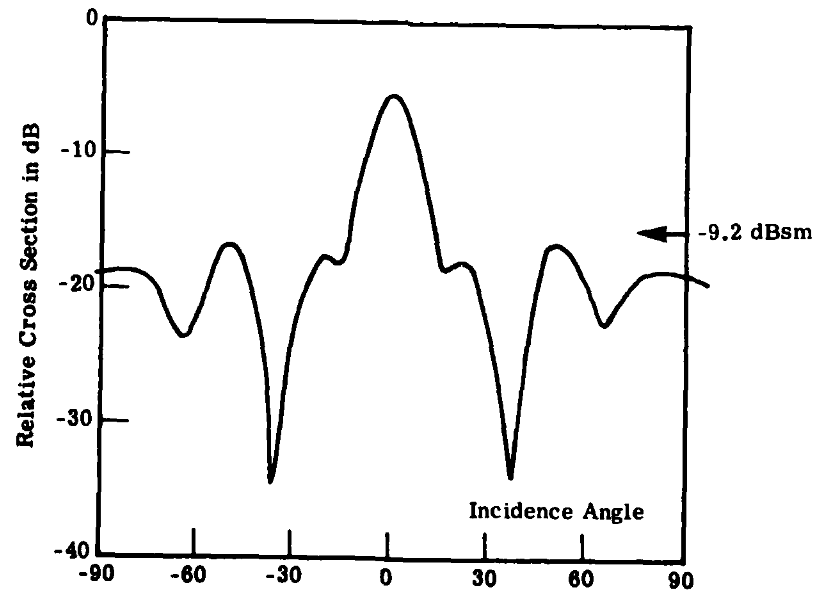


FIGURE 8. TM-46 FREE SPACE CROSS SECTION

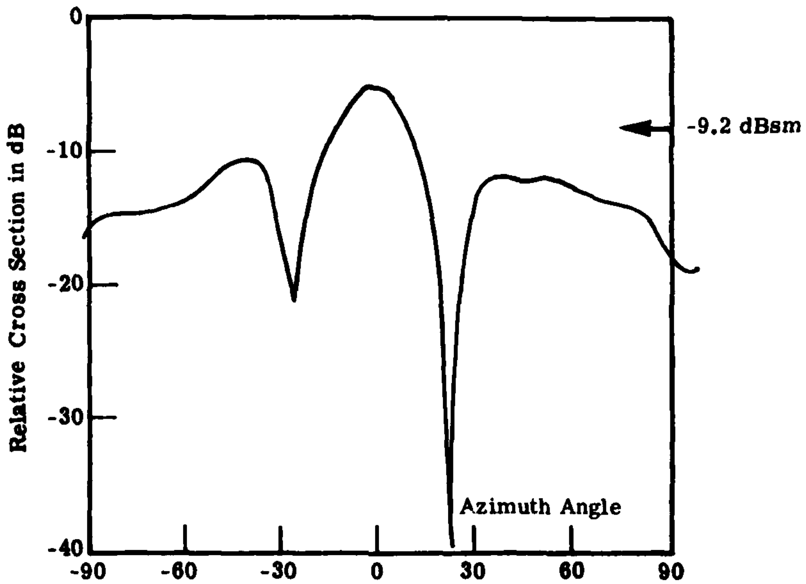


(a) 1.2 GHz, Vertical Polarization

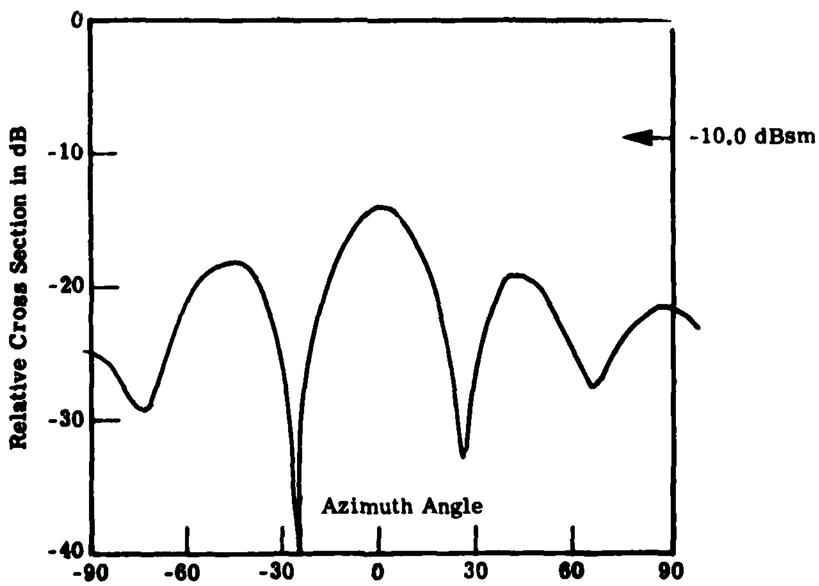


(b) 1.65 GHz, Horizontal Polarization

FIGURE 9. M-15 FREE SPACE CROSS SECTION



(a) TMD-B, 1.65 GHz, Vertical Polarization



(b) Simulated PM-60, 1.2 GHz, Vertical Polarization

FIGURE 10. FREE SPACE CROSS SECTIONS OF NON-METALLIC MINES

were then measured. Unfortunately, the RCS of the ground plane was so high that the addition of the mine did not significantly modify the total return. To no avail, absorber was added in an attempt to reduce the energy propagating around the back of the ground plane. Attempts to measure the mines on the vertical ground plane were then abandoned.

A second method of measuring the RCS of a mine on a ground plane was then adopted. The absorber was removed from the center section of the metal floor, and the mine was placed on a small turntable flush with the floor. Figure 7 shows the M-15 mine on top of the metal floor in the chamber. The depression angle for the measurements with the mines on the metal floor was 12.4°.

Difficulties were also encountered with the second method. For vertical polarization, energy propagated in the small gap between the platform and the metal floor beneath. The backscattering from the platform depended on the rotation angle because the gap did not remain uniform with angle. The scattering from the gap was too large for reliable measurements with vertical polarization; consequently, data could be collected only with horizontal.

Calibration with the mines on the ground plane was much more difficult than for the free-space measurements. For calibration, measurements of the returns from spheres were made with the spheres on the pedestal with the floor covered by absorber. The absorber on the floor was then removed and additional measurements of the returns from spheres and dihedrals were made, with the spheres on the ground plane and on a foam stand 3 in high. Figure 11 is a photograph of a sphere on the foam stand. The calibration level was found by calibrating the spheres on the ground plane using as a reference the free space sphere RCS with absorber on the floor. One difficulty with this approach is that removing the absorber from the floor or instrumentation drift during the time required to remove the absorber may

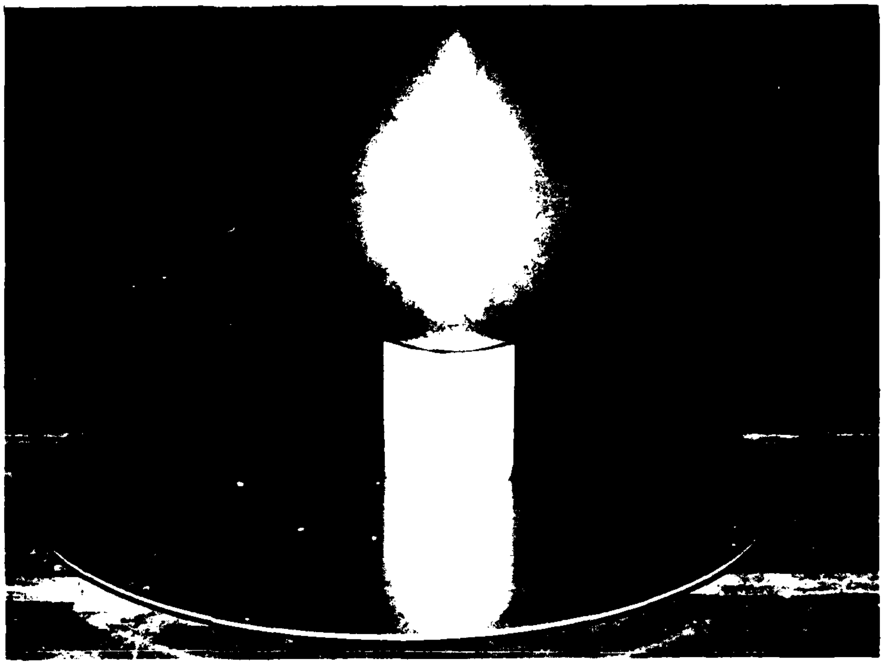
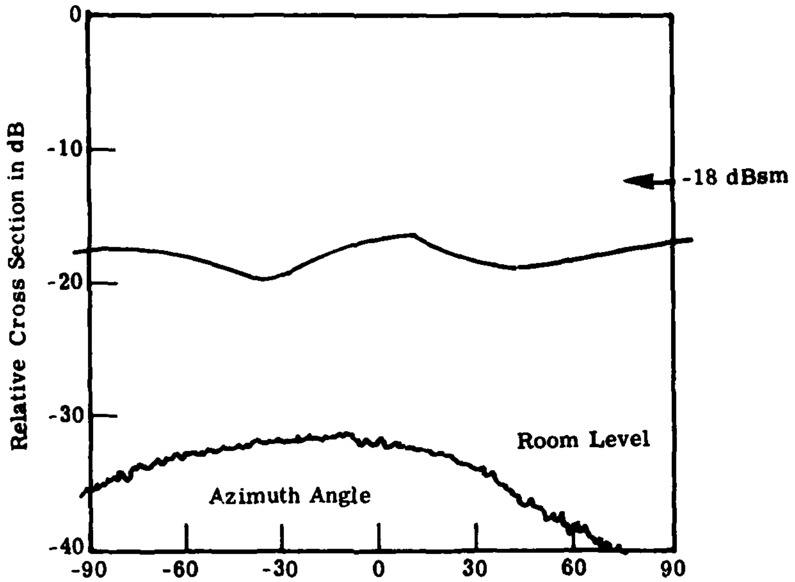


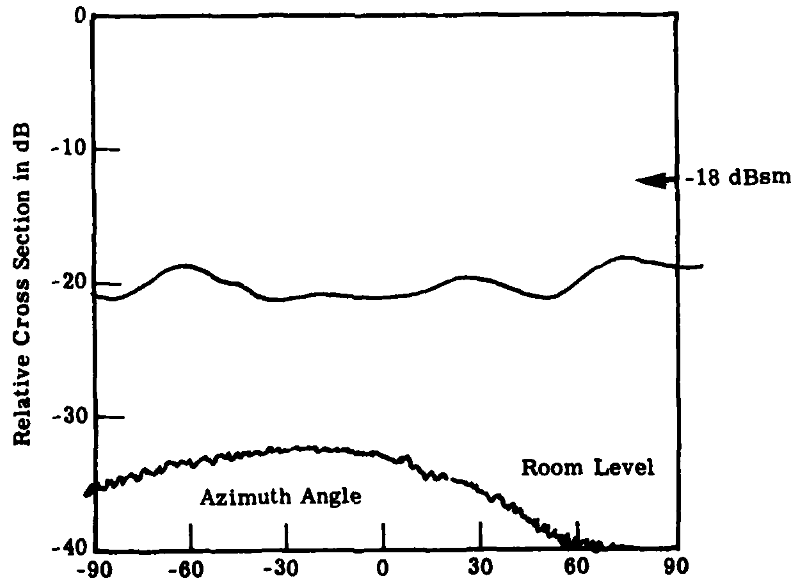
FIGURE 11. CALIBRATION SPHERE ON METAL GROUND PLANE

disturb the room balance. Figure 12 has sample curves of the RCS of the PM-60 and M-15 mines on the metal ground plane.

Calculating RCS values for the reference spheres in the presence of a metal ground plane is a difficult task because of resonance region interactions between the ground plane and the sphere. Calculations were made assuming that the sphere could be imaged as a point target in the ground plane, and these calculations were compared with measured values; however, the results did not agree for several of the spheres. It is uncertain whether the discrepancy should be attributed to the measurement technique or to the calculations.



(a) PM-60 With Simulated Fuze,
1.2 GHz, Horizontal Polarization



(b) M-15, 1.2 GHz, Horizontal Polarizaion

FIGURE 12. MINES ON METAL GROUND PLANE,
12.4° Depression Angle

3
L-BAND RESULTS

An internal ERIM memo has a detailed analysis of the L-band measurement results; that memo compares theoretical predictions of mine cross sections with measured results[2]. The reader should consult Reference 2 for more details on the material presented here.

At a typical L-band frequency, say 1.2 GHz, all of the mines measured possess resonance region characteristics. The resonance region is that part of the frequency spectrum for which the dimensions of the scatterer are comparable to the wavelength. Here the large and small wavelength approximations which are usually so useful to explain the nature of the scattering involved, are questionable and exact solutions for scattering in the resonance region are few and far between. The situation therefore forces one to rely primarily on measured data, particularly when a mine is on a ground plane. In spite of the fact that high frequency techniques are not strictly applicable in the resonance region, high frequency techniques were extended downward to obtain estimates of the RCS of the TM-46, M-15 and the TMD-B mines. When the theoretical estimates and the measured RCS values were compared, the theoretical estimates were acceptably close to the measured values[2].

The free-space measurements were made with the mine placed on a styrofoam column which is tapered to present a low RCS. The background clutter level was typically -40 dBsm. When the column was rotated, the mine was measured in a simulated vertical plane, 0 corresponding to the direction where the observer is looking straight down on top of the mine and 90° to the horizontal where the observer is looking at the side of the mine. The chart recordings such as

2. A. Maffett, L-Band RCS of Several Mines, Internal Memo, Electromagnetic Measurements, forthcoming.

Figures 8, 9, and 10 provide RCS information at any elevation angle of interest.

Table 1 summarizes the RCS at the cardinal aspects (0 and 90°) along with median and maximum RCS values. The median values were estimated by eye and might well be called "eyeball" medians. In genral the RCS of the two metal mines, the TM-46 and the M-15, are considerably higher than those of the nonmetallic mines.

Figure 13 is a composite of the measurements of all five mine types at 1.2 GHz, vertical polarization. The two metal mines, the TM-46 and the M-15 have approximately the same RCS at elevation angles less than 30° and near 90°, but the TM-46 has a dip near 60°. (The dip is gone at 1.65 GHz, see Figure 8.) The M-15 has the largest RCS of all the mines, and the PM-60 and M-19 have the lowest, less than -20 dBsm for all important elevation angles.

The RCS of the PM-60 was examined in some detail because a large number of simulated PM-60's have been made under the contract. Since the PM-60 uses either a metallic or non-metallic fuze, measurements were made to determine the effect of a metal fuze on the cross section. Since no real fuze was available, a simulated fuze and detonator assembly was machined out of aluminum with dimensions approximately equal to those of the real fuze and detonator. The fuze, which is approximately 10 cm, about half a wavelength long at L-band, is near resonance.

When the electric field of the incident wave was parallel to the long dimension of the simulated fuze, i.e., the RCS at the mine increased several dB at both 1.2 and 1.65 GHz . Figure 14 shows an 8 dB increase in the RCS at 1.65 GHz; at 1.2 GHz the increase was over 20 dB. When the incident electric field was normal to the long dimension of the simulated fuze, there was no significant increase. With an operational radar the increase in RCS will occur with vertical polarization.

TABLE 1
FREE SPACE MINE RCS VALUES IN dBsm
1.2 and 1.65 GHz
Horizontal and Vertical Polarizations

Freq. &	TM46				M15				TMD-B				M19			
Pol.	1.2H	1.2V	1.65H	1.65V	1.2H	1.2V	1.65H	1.65V	1.2H	1.2V	1.65H	1.65V	1.2H	1.2V	1.65H	1.65V
Top	-4	-5	-3	-2	-3	-3	0	1	-11	-10	-10	-8	-21	-26	-8	-5
Left Side	-16	-21	-21	-17	-15	-17	-13	-12	-16	-16	-14	-19	-26	-13	-16	-13
Right Side	-16	-17	-18	-18	-15	-16	-13	-12	-16	-14	-14	-20	-31	-15	-17	-13
Maximum	-2	-2	1	1	-1	-1	2	4	-11	-10	-9	-4	-17	-13	-8	-5
Median	-15	-17	-13	-10	-13	-14	-13	-11	-19	-16	-22	-14	-26	-23	-22	-15

TABLE 1 (Continued)
FREE SPACE MINE RCS VALUES IN dBsm
1.2 and 1.65 GHz
Horizontal and Vertical Polarizations

Freq. &	PM-60 No Simulated Fuze				PM-60 White Simulation				PM-60 With Simulated Fuze			
Pol.	1.2H	1.2V	1.65H	1.65V	1.2H	1.2V	1.65H	1.65V	1.2H	1.2V	1.65H	1.65V
Top	-14	-14	-20	-21	-13	-14	-18	-14	-13	-14	-20	-21
Left Side	-35	-17	-23	-32	-21	-30	-14	-32	-15	-25	-15	-33
Right Side	-35	-22	-24	-19	-22	-23	-15	-40	-15	-22	-16	-21
Maximum	-12	-13	-15	-14	-13	-13	-14	-14	-12	-14	-15	-14
Median	-26	-23	-24	-20	-22	-23	-22	-22	-18	-21	-20	-21

The analysis of the calibration spheres above the metal ground plane predicted that the ground plane would increase the RCS of the mines compared with free space. With the PM-60 the presence of the ground plane did increase the RCS but the return with the ground plane was much lower than the free space return for the metal mines, the TM-46 and the M-15. These anomalous results have not been satisfactorily explained. Because of unanswered questions we have not tabulated any of the ground plane measurement results. In practice the mines will be on a dielectric ground plane (the terrain), not a metal ground plane.

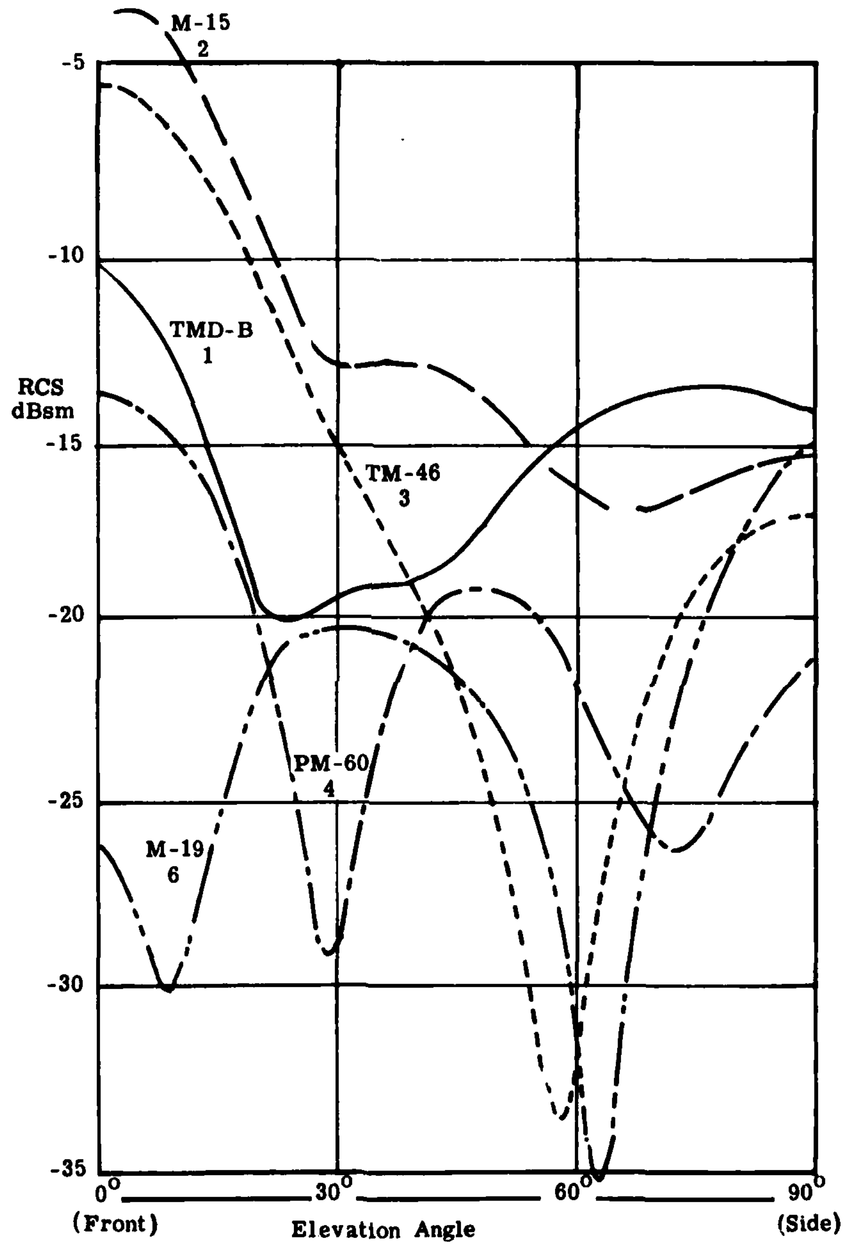
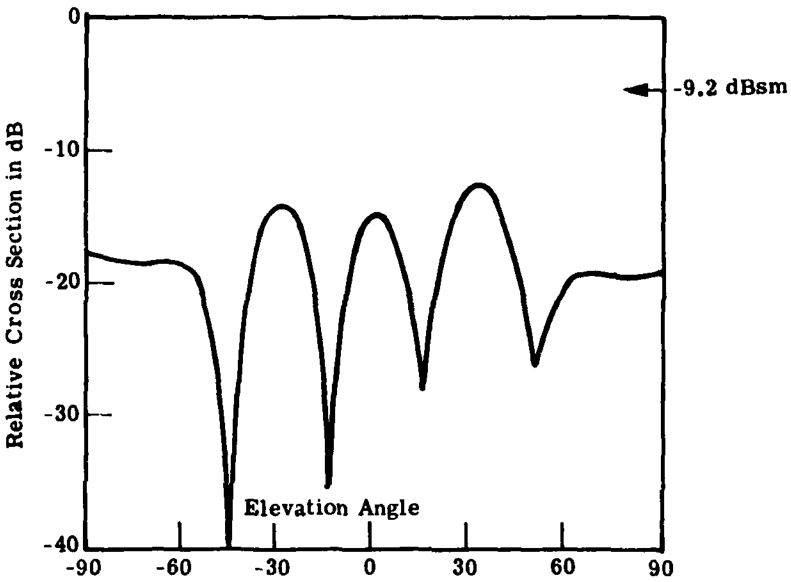
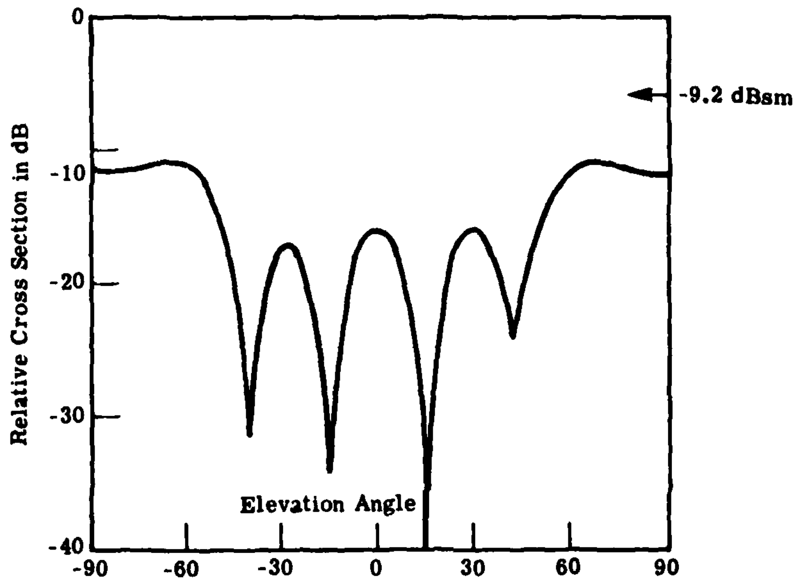


FIGURE 13. COMPOSITE OF FREE SPACE MINE MEASUREMENTS. 1.2 GHz, Vertical Polarization. The numbers with the mines are the run numbers. 0° = Front of mine, 90° = Side of mine.



(a) Mine Alone

FIGURE 14. PM-60 CROSS SECTION WITH SIMULATED FUZE. 1.65 GHz, Horizontal Measurement Polarization



(b) Mine with Simulated Fuze

FIGURE 14. (Cont.) PM-60 CROSS SECTION WITH SIMULATED FUZE. 1.65 GHz, Horizontal Measurement Polarization

4
SIGNAL-TO-CLUTTER RATIO CALCULATIONS AND MINE DETECTABILITY

The purpose of the experimental measurements and theoretical estimates of mine RCS is to provide data for modeling a mine in a clutter background. A minefield can be detected if the clutter-to-noise ratio is high enough so that the radar can detect individual mines. Alternatively, a radar can detect a minefield by the increase in the background reflectivity caused by the presence of the mines. In either method we must know σ_o, the RCS per unit area of terrain. σ_o is a function of frequency, depression angle, terrain and polarization.

L-band σ_o data is available from the Ohio State University[3] and from the NRL four frequency radar system[4], an extrapolation of σ_o data has also been made by Crispin and Maffett[5]. Figure 15 shows three data sets from Reference 4 along with the estimated values from Reference 5. The estimated value for desert is about -30 dB; however σ_o will probably increase 10 dB for areas typical of Eastern Europe. For example, the average return for rural New Jersey terrain is about 10 dB higher than Arizona desert.

The average clutter return C is

$$C = \sigma_o A$$

where A is the area of the radar resolution cell. Figures 16 and 17 show the ratio of S+C/C with σ_o = 0.01 and 0.001 for the M-15, TM-46, and the PM-60 as a function of A. S is the median RCS. A

3. T. L. Oliver and W. H. Peake, Radar Backscattering Data from Agricultural Surfaces, The Ohio State University, Electro Science Lab Tech. Rept. 2440-5, Feb. 1969.

4. J. C. Daley, et al., NRL Terrain Clutter Study, Phase II, Naval Research Lab., Report 6749, Oct. 1968.

5. J. W. Crispin, Jr., and A. L. Maffett, Backscattering from Terrain, KMS Industries, Rept. KMSTR-A1F-767, July 1967.

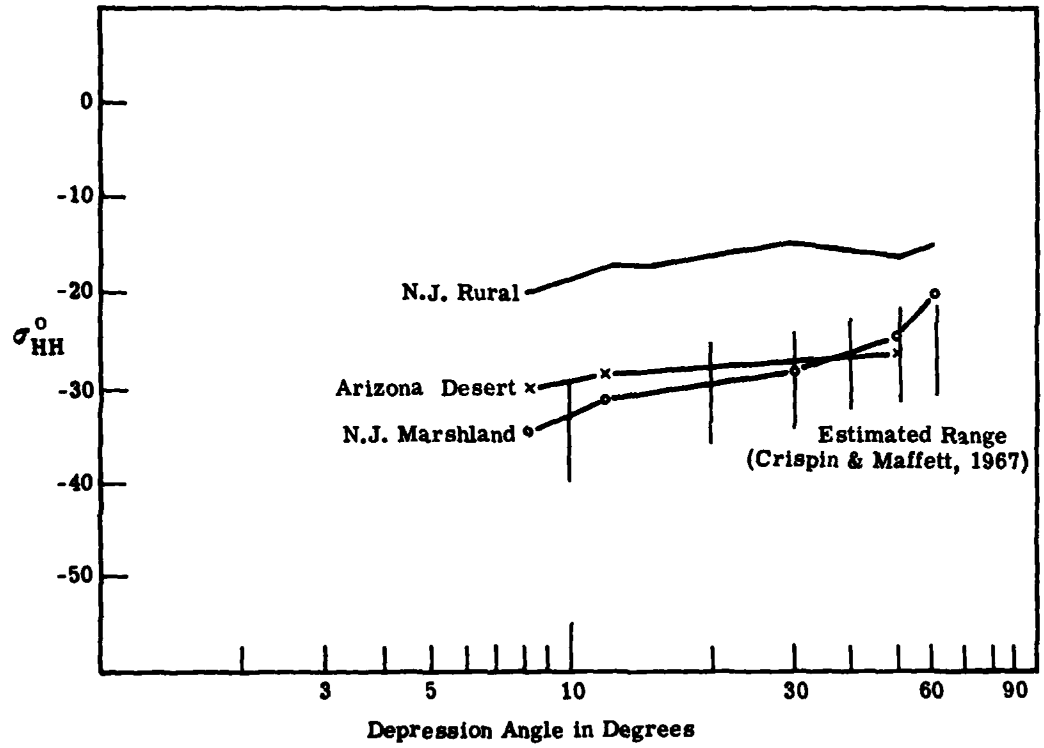


FIGURE 15. σ^o_{HH} FOR ARIZONA DESERT (x), N.J. MARSHLAND, and N.J. RURAL AT L-BAND (1228 MHz) (Daley et al, 1968, p. 14)

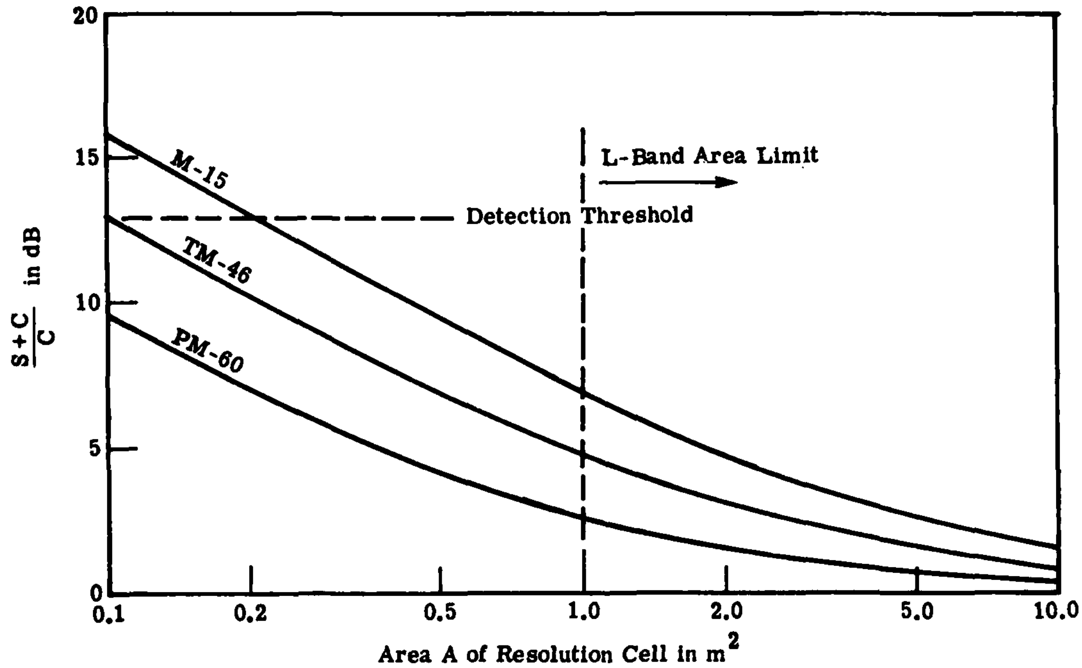


FIGURE 16. $\frac{S+C}{C}$ VERSUS A, $\sigma_o^o = 0.01$

S = -14 dBsm M-15
-17 dBsm TM-46
-21 dBsm PM-60

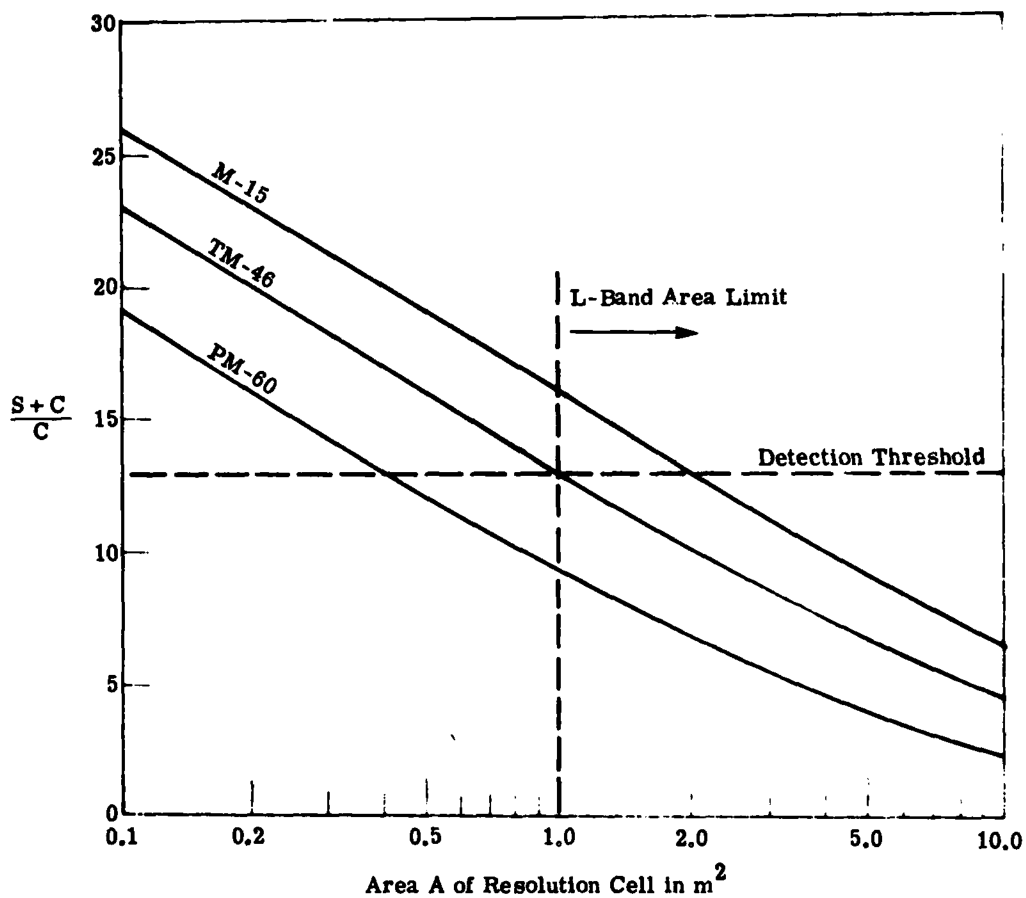


FIGURE 17. $\frac{S+C}{C}$ VERSUS A, $\sigma_o^o = 0.001$

σ_o-value of 0.01 is typical of the reflectivity of an Eastern European terrain at the higher depression angles; a value of 0.001 is typical of desert terrain or Eastern Europe at low depression angles. Only the M-15 has a S+C/C ratio over the detection threshold of 13 dB for A greater than or equal to 1 m^2 for σ_o = 0.001.

There is a practical limit of about 150 MHz on the bandwidth that can be transmitted at L-band; with this limit the range resolution will be 1 m or more. There are other restrictions which limit the azimuth resolution. The combined effect of both restrictions is a practical limit of about 1 m^2 for the area of the resolution cell for an L-band synthetic aperture radar. With the 1 m^2 limit the two foreign mines cannot be detected as individual targets in a typical European background.

In the second method of detecting mines, there is an increase in the average background reflectivity with mines present. In this case, a typical mine density is assumed for a terrain with known reflectivity characteristics. Let σ_M represent the RCS of the mine in question and D its density. Then the average reflectivity of the terrain becomes the sum $\sigma_M D + \sigma_o$; detection occurs if $\sigma_M D + \sigma_o$ is sufficiently greater than σ_o.

Figures 18 and 19 show the effect of placing TM-46 and PM-60 mines on grass covered terrain typical of Eastern Europe. The σ_o-data for these figures is from Reference 2 for a frequency of 1.8 GHz; it is representative of vertical and horizontal polarizations. For Figure 18, the polarizations can be either horizontal or vertical. For Figure 19, the PM-60 RCS selected are those with a metal fuze; vertical polarization where the mine RCS is maximum has been assumed. Figures 20-22 show similar curves for the "broken desert" background of Figure 15. For all the figures a mine spacing of 5 m was assumed so that the density D was 0.04. Unfortunately, Reference 2 has no data for bare ground of any type.

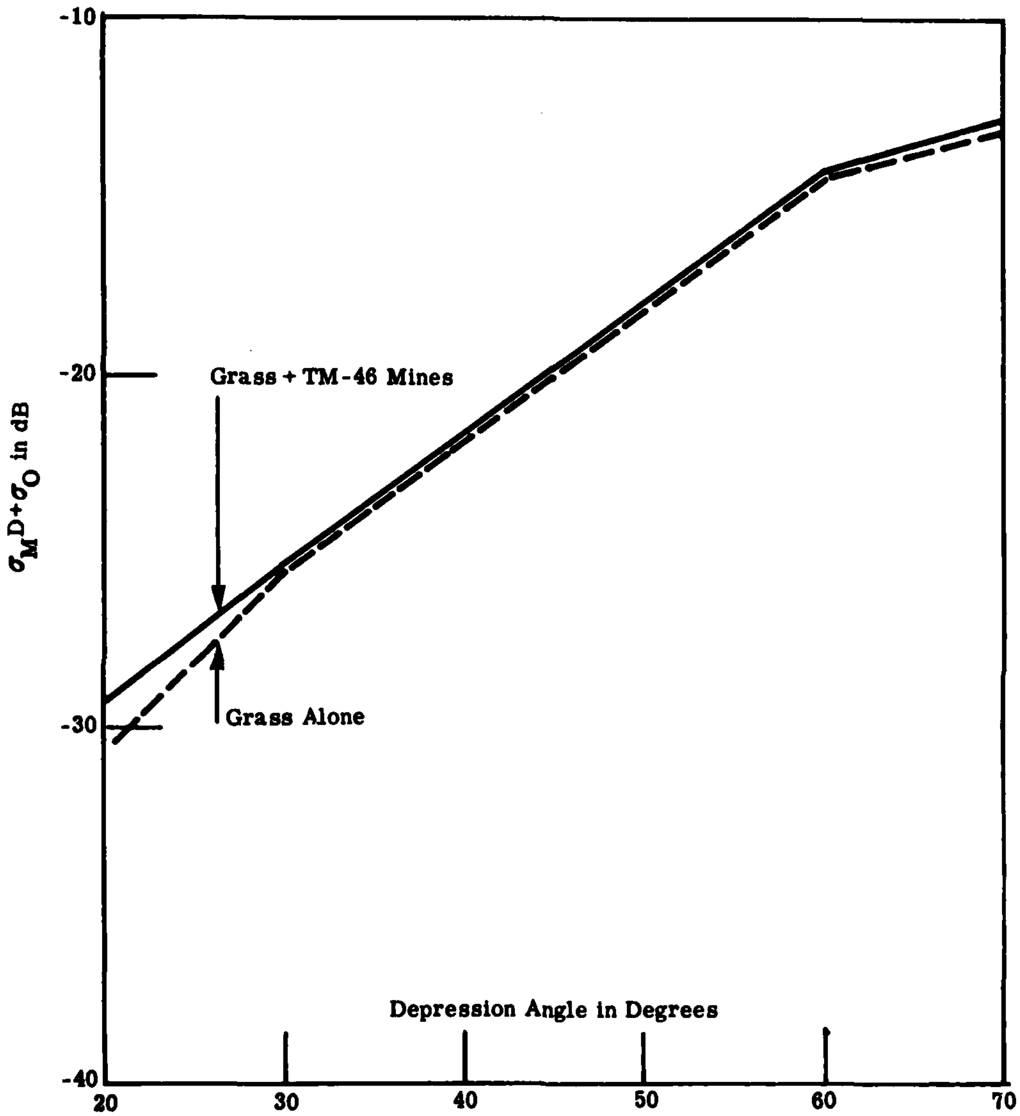


FIGURE 18. AVERAGE BACKGROUND REFLECTIVITY WITH TM-46 MINES ON GRASS. Mine Spacing = 5m, D = 1/25.

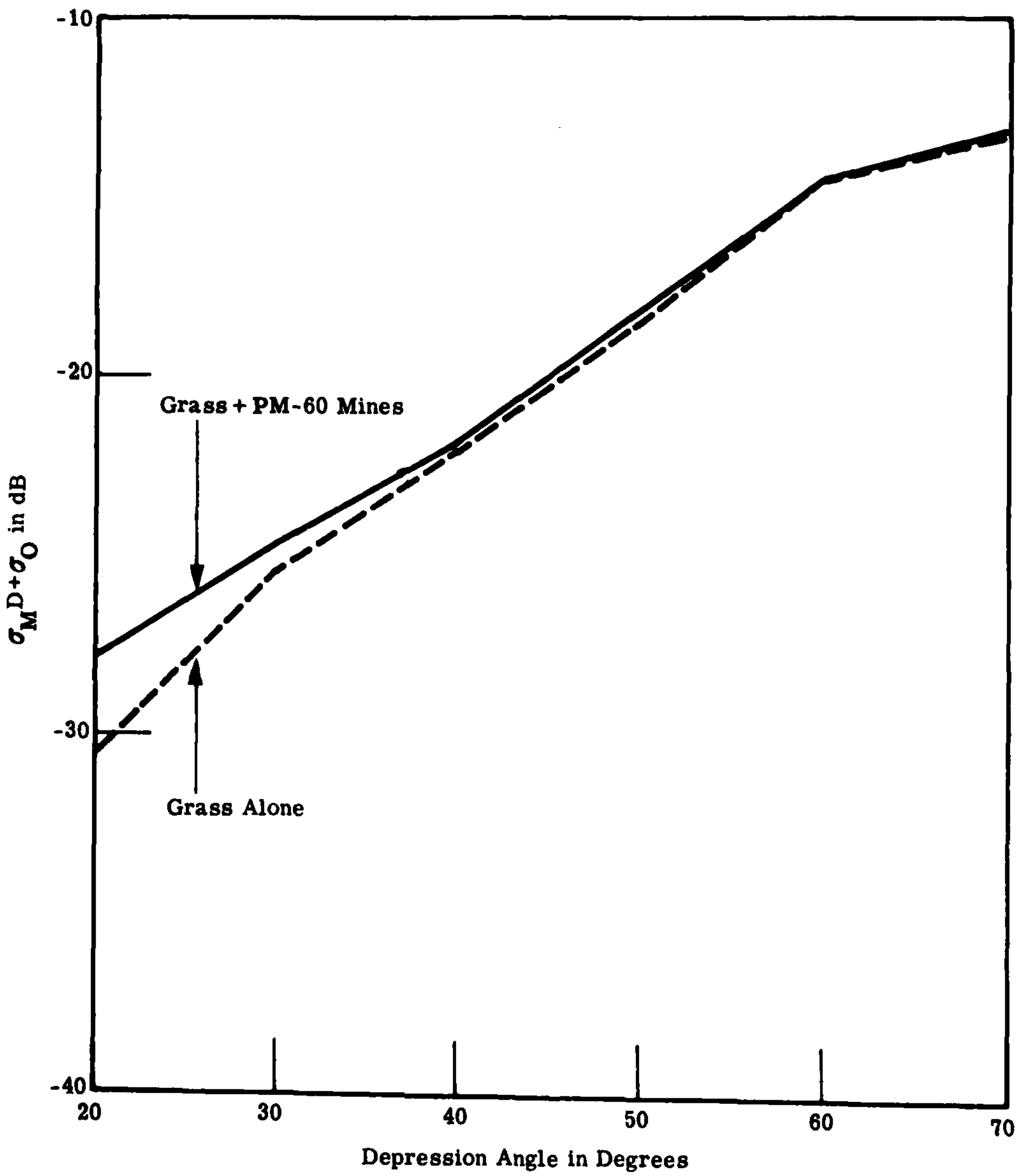


FIGURE 19. AVERAGE BACKGROUND REFLECTIVITY WITH PM-60 MINES ON GRASS. Mines with metal fuzes, Vertical Polarization. Mine spacing = 5m.

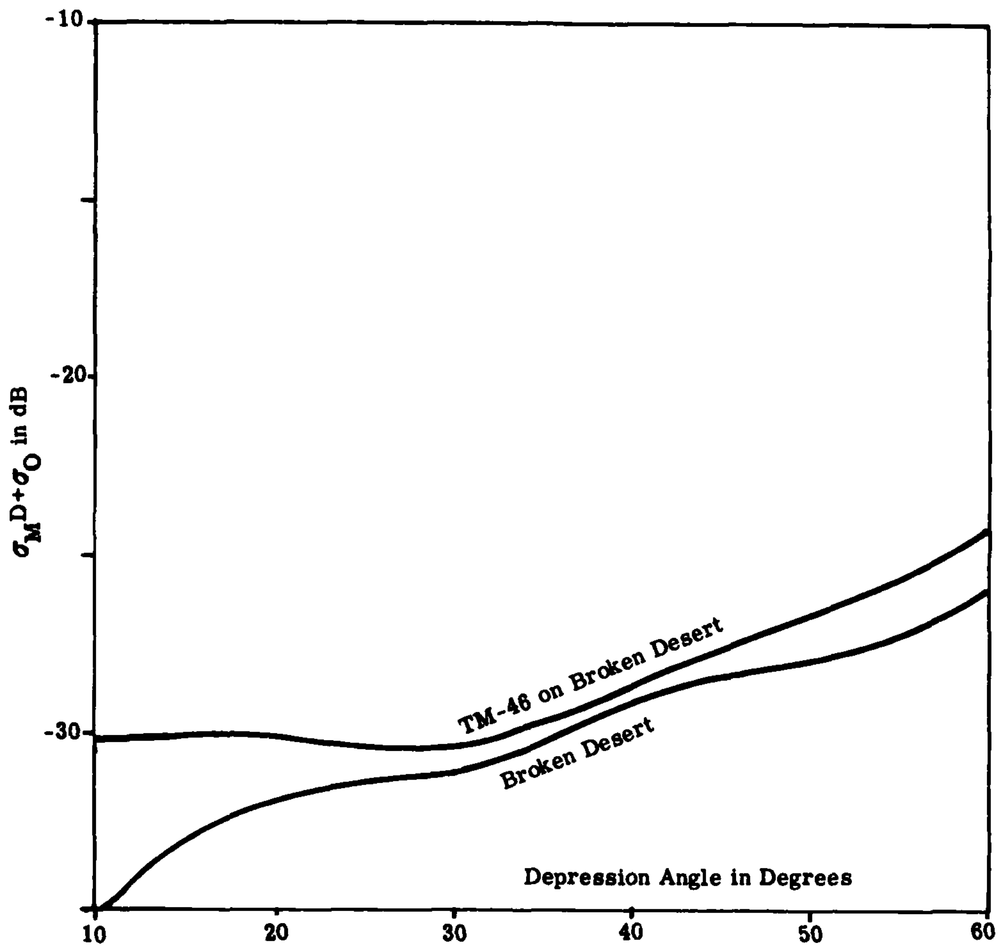


FIGURE 20. AVERAGE BACKGROUND REFLECTIVITY WITH TM-46 MINES ON BROKEN DESERT. Mine spacing = 5m.

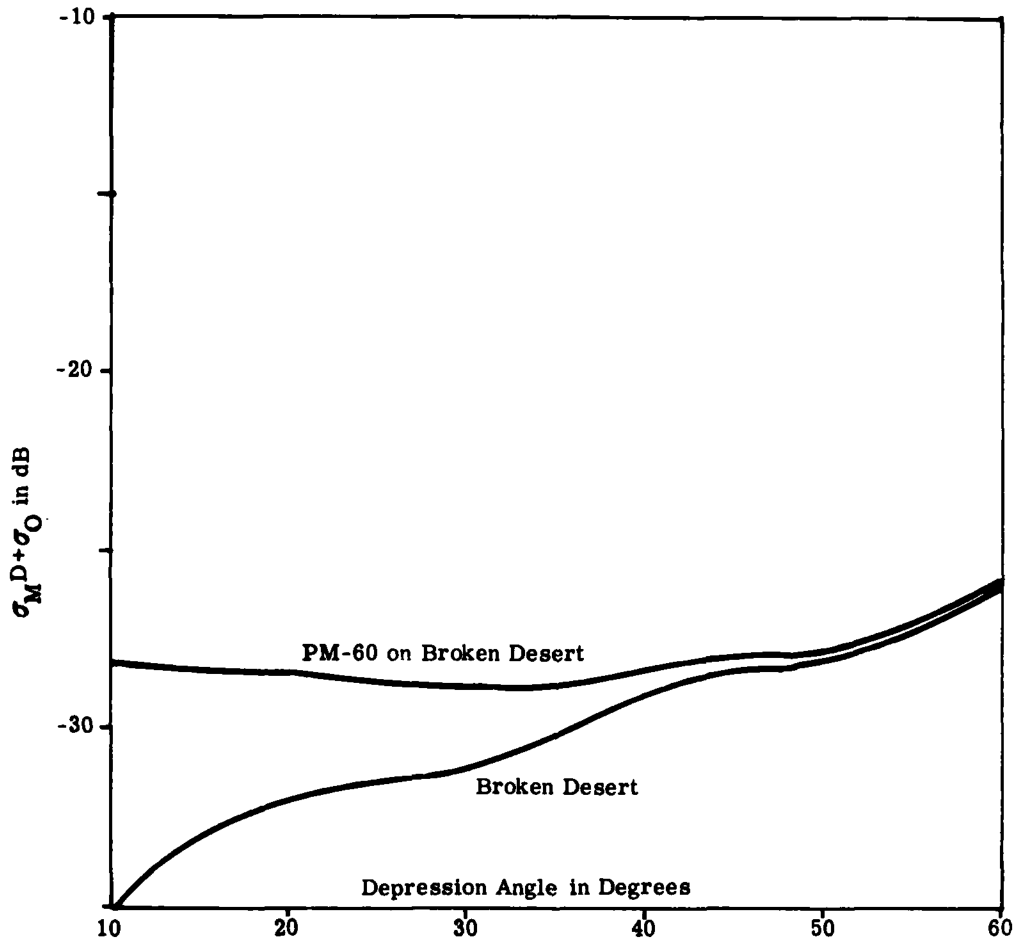


FIGURE 21. AVERAGE BACKGROUND REFLECTIVITY WITH PM-60 MINES ON BROKEN DESERT. Mines with metal fuzes, Vertical Polarization. Mine spacing = 5m.

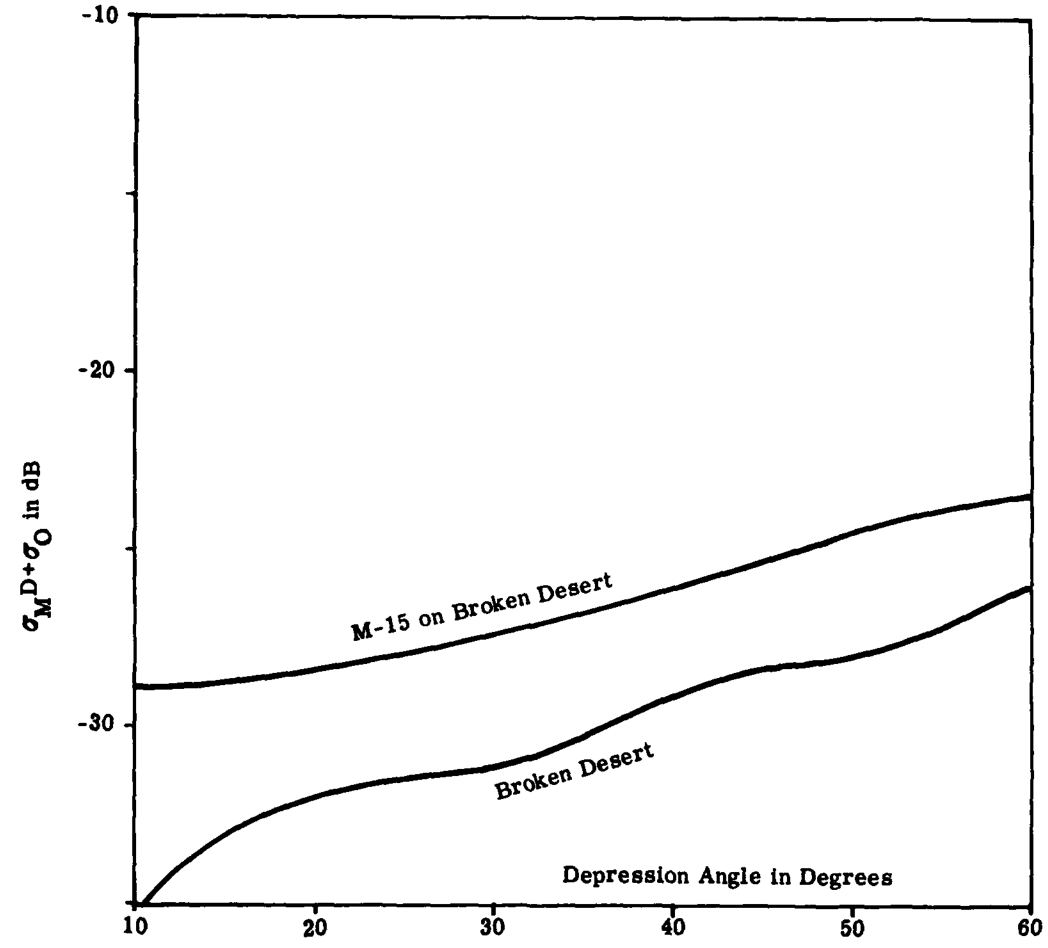


FIGURE 22. AVERAGE BACKGROUND REFLECTIVITY WITH M-15 MINES ON BROKEN DESERT. Mine spacing = 5m.

For all of the curves the mines increase the average background reflectivity the most at low depression angles. In the grass background typical of Eastern Europe, the difference in background reflectivity with the mines is small, preventing detection. In a desert environment the TM-46 and PM-60 should be detectable at the lower depression angles; the M-15, which has higher cross section, is detectable at all depression angles. In general, the increase in background reflectivity with surface mines in the L-band frequency region is approximately the same as the increase at X-band reported earlier[1].

5
THE X-BAND MEASUREMENTS

Although other changes have been made besides the addition of the antenna tower, shown in Figure 23, the basic X-band instrumentation and operating parameters are the same as those used in 1977. Consult Ref. 1 for more details on the instrumentation. The ERIM rotary platform high resolution imaging system was used for the measurements; with this system the transmitted signal is wide band chirp. For the mine RCS measurements the mines were placed at the center of the platform, the received signal was integrated using a spectrum analyzer with the proper control settings, and recordings of total RCS versus azimuth angle were obtained with a chart recorder connected to the spectrum analyzer. The RCS values obtained are the average over a 3 GHz band centered at 10 GHz. The distance from the antennas to the center of the platform where the mines were placed was 90 ft. Vertically and horizontally polarized data were collected.

Figures 24 and 25 show the TM-46 and the PM-60 mines which are of prime interest in the program. The TM-46 is at the center of a metal ground plane 4 ft square; this ground plane was used at the 22^{o} and 10^{o} depression angles because the surface of the platform was not flat. Without the ground plane the RCS varied erratically with the rotation angle. The PM-60 in Figure 25 was filled with wax to simulate the dielectric constant of the explosive it normally contains.

During the measurements a large transmitter horn was employed to narrow the area illuminated and reduce the background clutter. For calibration returns from 15 and 5 dBsm corners, a 1 dBsm top hat, and 14 inch and 6 inch spheres were marked on the chart, and the straight line which fit the experimental points best was used to establish the calibration level of 1 m^2.

FIGURE 23. PHOTOGRAPH OF ROTARY PLATFORM AND TOWER

FIGURE 24. TM-46 ON METAL GROUND PLANE

FIGURE 25. PM-60 ON PLATFORM

Figures 26-29 are sample RCS measurements from four of the mines. Figure 26 has a plot of the TM-46 RCS (vertical scale) versus azimuth angle (horizontal scale) for the 22^{o} depression angle with vertical polarization. Except for a notch near the center of the curve caused by a plastic plug near the handle, the cross section is about -4 dBsm. Figure 27 is a similar chart recording for the M-15 mine which has an average RCS of about -1 1/2 dB. The return from the ground plane alone and the background is also plotted in Figure 27. The background clutter level varied with the depression angle; at the 22^{o} depression angle it was about -24 dBsm.

Figure 28 has the RCS of the PM-60 along with the background clutter for a 3^{o} depression angle with vertical polarization; Figure 29 shows the RCS of a simulated PM-60 which was specially manufactured for use in the test array. Although there is some difference in the fine grain structure, the average levels are essentially identical; the mean RCS is -21 or -22 dBsm.

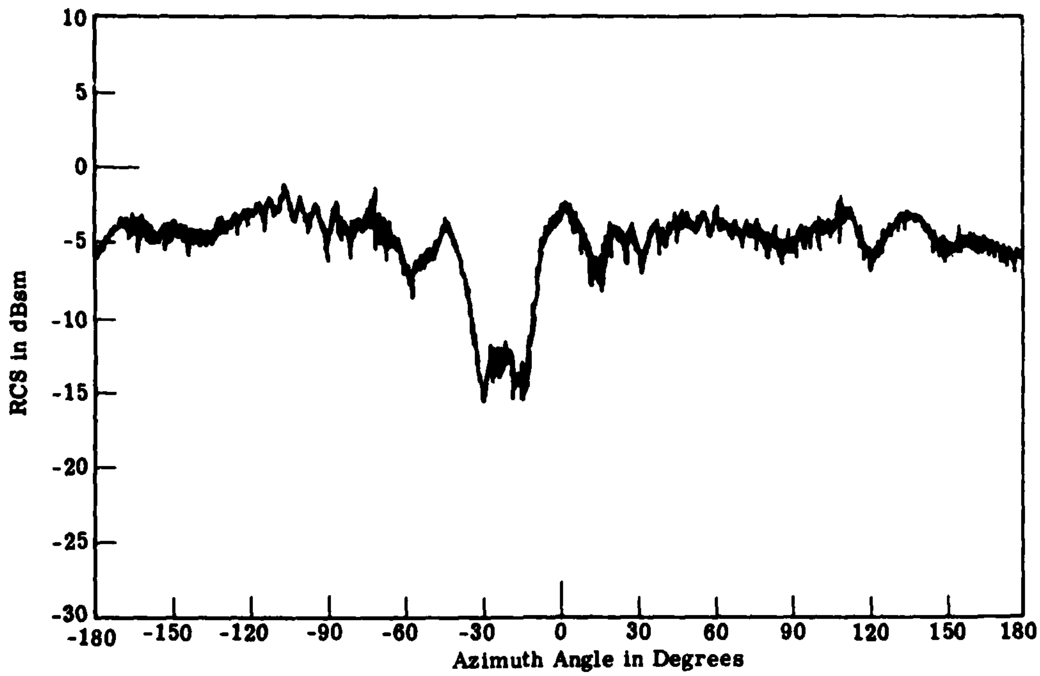


FIGURE 26. RCS OF TM-46 ON METAL GROUND PLANE. Vertical Polarization, 22^{o} Depression Angle, Chart 21, 9 May 1979.

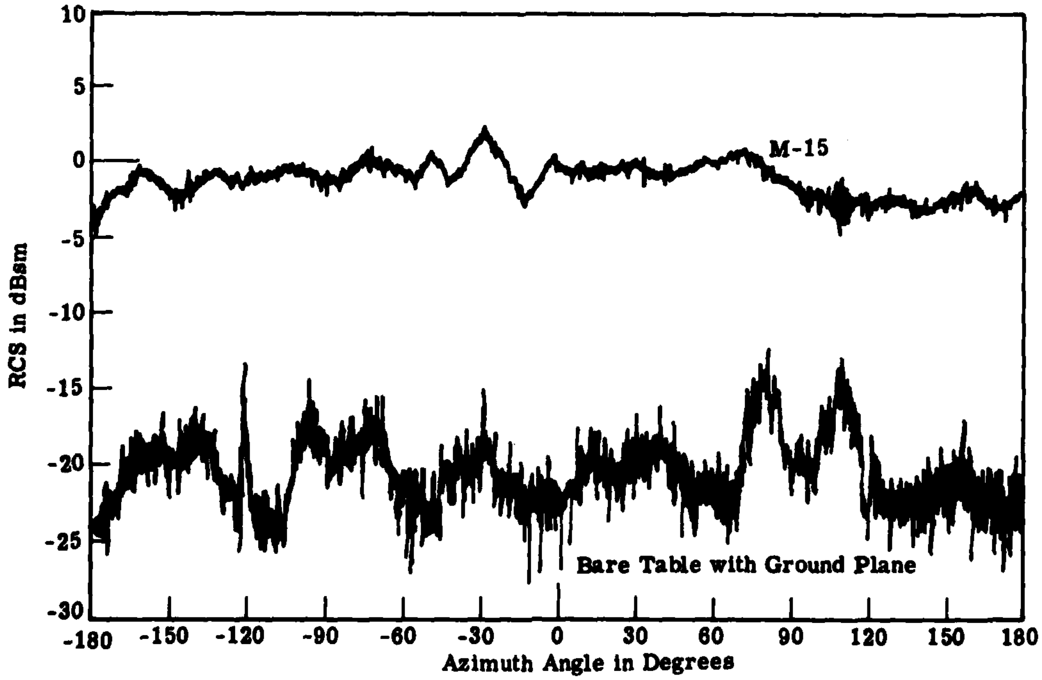


FIGURE 27. RCS OF M-15 ON METAL GROUND PLANE. Vertical Polarization, 22^{o} Depression Angle, Chart 22, 9 May 1979.

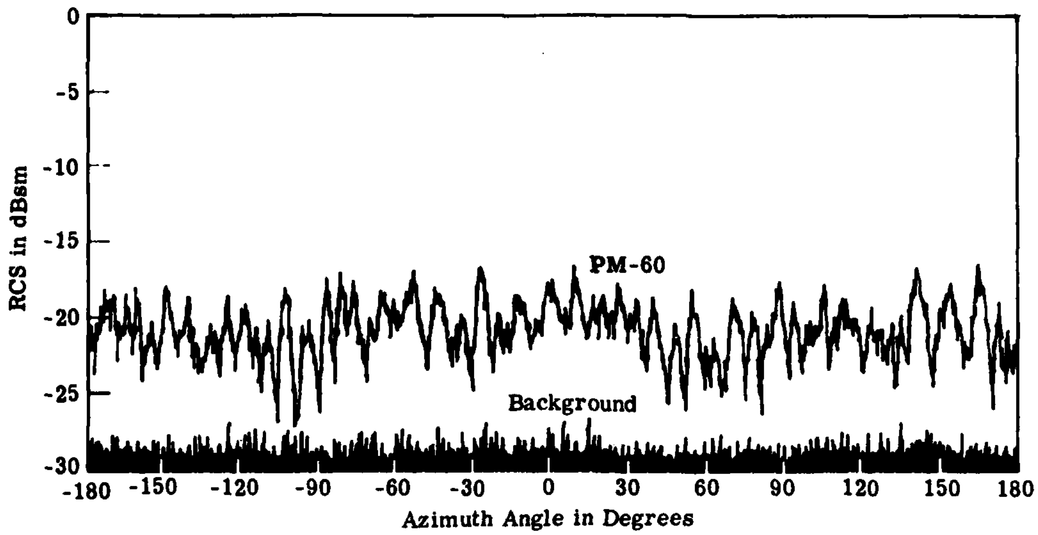


FIGURE 28. RCS OF PM-60 AND BACKGROUND. Horizontal Polarization, 3^{o} Depression Angle, 23 May 1979.

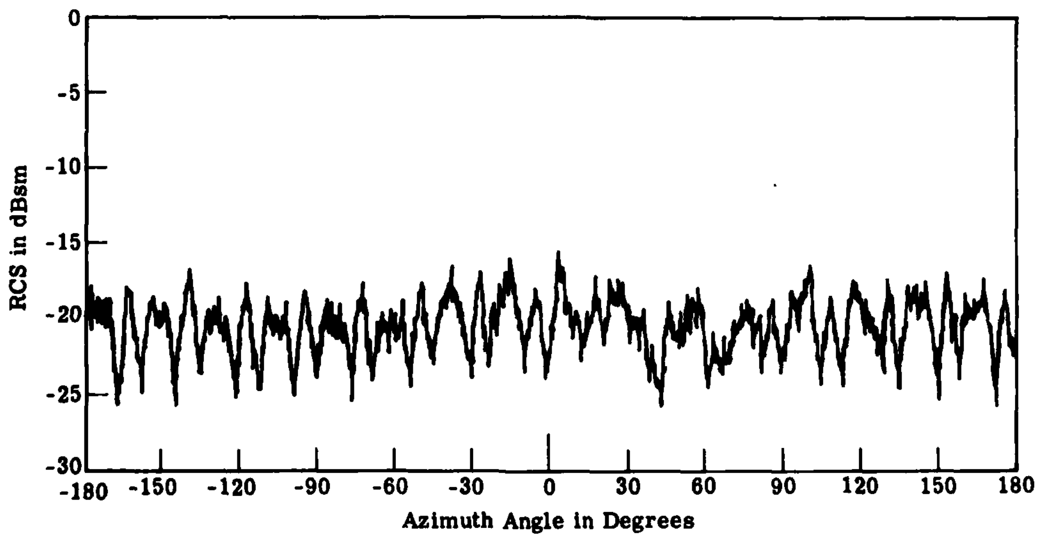


FIGURE 29. RCS OF SIMULATED PM-60 FROM VENDOR. Horizontal Polarization, 3^{o} Depression Angle, 23 May 1979.

6
SUMMARY OF MEASUREMENT RESULTS

Table 2 lists X-band median RCS values for the five mines measured at depression angles of 3°, 10°, and 22°; the mines were on the metal ground plane at the 10° and 22° angles. The table is valid for both horizontal and vertical polarizations, since there was little change in the RCS with polarization. Since the TMD-B rectangular Soviet mine, and the M-19 plastic American mine have rather high peaks at aspects normal to the sides, the maximum peak RCS are also given parenthically for these two mines. There is a consistent trend of increasing RCS with increasing elevation angle for all five mines. For the TMD-B and the M-19 where the peaks are so pronounced, the same trend in the peak values is evident. The metal ground plane increases the RCS from what it would have been on the plywood platform surface.

RCS measurements of the PM-60 were made with and without the simulated metal fuze and detonator. The presence or absence of the simulated fuze made no difference in the X-band RCS. The simulated fuze is, of course, not a resonant scatterer at X-band as it is at L-band. Measurements of simulated PM-60's supplied by MERADCOM as well as the vendor for the mine array indicated no difference in RCS levels compared with the real PM-60.

Some of the 1977 measurements were made with the mines on sand ramps to increase the effective depression angle to 10°. Table 3 has a comparison of median and maximum values for the 10° depression angle for the 1977 and 1979 measurements; the results agree remarkably well. Where theoretical models have been devised and studied, the table includes the results which compare reasonably well.

Table 3 also has the results of the L-band free-space measurements. There are certain anomalies between theory and measurements such as the variation of RCS with frequency. For the TMD-B and M-19

TABLE 2. X-BAND MEDIAN MINE RCS

Mines on Ground Plane
Horizontal or Vertical Polarization
Values in dBsm

Depression	PM60	TM46	M15	TMD-B	M-19
3°	-25	-15	-10	-25(-3 peak)	-25(-9 peak)
10°	-20	- 4	- 3	-25(0 peak)	-15(2 peak)
22°	-15	- 2	- 2	-22(3 peak)	-15(5 peak)

TABLE 3
MINE RCS FOR 10° DEPRESSION ANGLE (dBsm)

X, L Freq.	PM-60 Median	PM-60 Max.	TM-46 Median	TM-46 Max.	M-15 Median	M-15 Max.	TMD-B Median	TMD-B Max.	M-19 Median	M-19 Max.
X, Measured 1977	-23	-15			-6	-5	-25	-3	-20	-4
X, Measured 1979	-20	-13	-4	-1	-3	-1	-25	2	-17	4.5
X, Theory	-23	-20			-1	1	-25	-3	-16	0
L, Measured 1979	-22	-14	-15	-2	-13	-1	-19	-10	-23	-13

mines, the theoretical models predict an RCS decrease of 9 dB from X to L-band; the actual decrease in the measured values are 7-12 dB for the TMD-B and 9-18 for the M-19. Theory predicts very little change of RCS from X to L-band for the PM-60; the measurements in Table 2 support this condition. In the cases of the TM-46 and M-15 mines the theoretical models indicate a RCS fall off of about 9 dB from X to L-band; the median measured data support this trend generally, but the maximum values at X and L-band do not for reasons which are not clear.

Certain liberties have been taken in the comparisons of the X and L-band data which may or may not be justifiable. The L-band data are free-space data, while the X-band measurements were made on a ground plane. It is believed that a ground plane, particularly a metallic one, will augment the RCS of a mine, but uncertainty on the change exists for both bands.

7
SUMMARY AND CONCLUSIONS

Free-space cross-section measurements of several mines were made at two frequencies in L-band, 1.2 and 1.65 GHz. The median cross sections of the mines of most interest, the Soviet TM-46 and East German PM-60 were about -13 and -20 dBsm, respectively. The RCS of the TM-46 was several dB lower than that measured at X-band; however, the TM-46 was on a ground plane for the X-band measurements. The RCS of the PM-60 was approximately the same as at X-band. (The measured RCS values vary considerably with aspect angle, a fact not evident from the median values quoted above.) The metal fuze in the PM-60 raises the L-band RCS when the incident electric field is parallel to the fuze at side aspects.

Measurements with the mines on ground planes were also made, but calculated RCS values for the calibration spheres did not agree with measured values. Because of measurement uncertainties and the fact that a metal ground plane does not simulate terrain which acts as a dielectric ground plane, free space RCS values were used in the detectability calculations. The conclusions that follow are based on the free-space RCS values.

After calculations were made to determine the detectability of individual mines in a clutter background typical of Eastern Europe, it was concluded an L-band radar does not have resolution fine enough to detect individual mines.

Mine detectability via an increase in the average background reflectivity was also investigated. In most European environments the mines do not increase the reflectivity sufficiently to permit detection; however, detection is likely in the desert at the lower depression angles where the background reflectivity is less. The L-band study did not cover special processing techniques, the detectability of minelayer furrows or other ground disturbances, and no conclusions were reached regarding these factors or inferential detection.

A conventional anechoic chamber is poorly suited to measuring the RCS of mines on ground planes in the L-band frequency region. If additional measurements are performed in the future, special instrumentation should be used for the ground plane measurements. Such equipment should have a narrow antenna beam and a pulsed signal to discriminate against background clutter. Modeling mine cross sections theoretically is quite difficult at L-band where the mine dimensions are comparable to the wavelength, and a significant effort would be needed to formulate a usable theoretical model.

The X-band RCS measurements made in 1979 were consistent with those performed in 1977. The American M-15 metal mine was found to be a good simulation for the Soviet TM-46; at a 10° depression angle both mines have a RCS of -3 or -4 dBsm. The PM-60 simulations for the mine array tests made by the vendor had RCS values very close to those measured for the real PM-60; at a 10° depression angle the RCS of both was about -20 dBsm. The simulated metal fuze had no effect on the PM-60 X-band RCS at either horizontal or vertical polarization.

Additional theoretical work is needed to adequately explain the RCS change with frequency (X to L-band) and to account for scattering interaction between a mine and its ground plane, particularly at L-band.

DISTRIBUTION LIST

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